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# ============================================================================
# R Script: US Tourism-CO2 Partial Wavelet Analysis_CIT Research Letters
# Author: S. CHANG
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# 1. 安裝與載入必要套件
if(!require(biwavelet)) install.packages("biwavelet")
if(!require(tidyverse)) install.packages("tidyverse")
if(!require(readr)) install.packages("readr")
if(!require(tseries)) install.packages("tseries") # 用於統計檢定

library(biwavelet)
library(tidyverse)
library(readr)
library(tseries)

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# ============================================================================
# 2. 匯入數據 (請選擇 US_Full_Data.csv)
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# ============================================================================
# 會跳出視窗讓您選擇檔案
csv_path <- file.choose()

# 讀取 CSV
raw_data <- read_csv(csv_path, show_col_types = FALSE)

# 強制重新命名欄位 (確保名稱與程式碼一致)
# 假設順序為: Year, Month, CO2, DOMESTIC, INTERNATIONAL, TOTAL, EPU
if(ncol(raw_data) >= 7) {
    colnames(raw_data)[1:7] <- c("Year", "Month", "CO2", "DOMESTIC", "INTERNATIONAL",
"TOTAL", "EPU")
} else {
    stop("錯誤：您的 CSV 檔案欄位少於 7 欄，請檢查是否已將 EPU 貼入 G 欄。")
}

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# ============================================================================
# 3. 數據前處理 (Log-Difference)
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# ============================================================================
# 建立日期與取對數差分 (確保平穩性)
data_clean <- raw_data %>%
    mutate(
        # 建立日期格式 (設為每月 1 號)
        Date = as.Date(paste0(Year, "-", Month, "-01")),

        # 轉為數值並取 Log
        ln_CO2   = log(as.numeric(CO2)),
        ln_Total = log(as.numeric(TOTAL)),
        ln_Dom   = log(as.numeric(DOMESTIC)),
        ln_Intl  = log(as.numeric(INTERNATIONAL)),
        ln_EPU   = log(as.numeric(EPU))
    ) %>%
    na.omit() %>%
    mutate(
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            # 取差分 (Difference)
            d_CO2   = c(NA, diff(ln_CO2)),
            d_Total = c(NA, diff(ln_Total)),
            d_Dom   = c(NA, diff(ln_Dom)),
            d_Intl  = c(NA, diff(ln_Intl)),
            d_EPU   = c(NA, diff(ln_EPU))
        ) %>%
        na.omit() %>%
        arrange(Date)

# 準備小波矩陣 (cbind: 時間索引, 數值)
t <- 1:nrow(data_clean)
y_co2 <- cbind(t, data_clean$d_CO2)   # Y: CO2
z_epu <- cbind(t, data_clean$d_EPU)   # Z: EPU (Control)
x_total <- cbind(t, data_clean$d_Total)
x_dom   <- cbind(t, data_clean$d_Dom)
x_intl  <- cbind(t, data_clean$d_Intl)

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# 4. 產出 Table 1: 敘述性統計與單根檢定
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# 4. 產出修正後的 Table 1: 敘述性統計與多重單根檢定 (ADF, PP, KPSS)
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calc_stats_revised <- function(x) {
    mean_val <- round(mean(x), 4)
    sd_val   <- round(sd(x), 4)
    min_val  <- round(min(x), 4)
    max_val  <- round(max(x), 4)

    # Jarque-Bera 常態性
    jb <- jarque.bera.test(x)
    jb_stat <- paste0(round(jb$statistic, 2), ifelse(jb$p.value<0.01, "***", ifelse(jb$p.value<0.05, "**",
""")))

    # ADF 平穩性 (H0: 有單根/不平穩)
    adf <- adf.test(x)
    adf_stat <- paste0(round(adf$statistic, 2), ifelse(adf$p.value<0.01, "***", ifelse(adf$p.value<0.05,
"**", """)))

    # PP 平穩性 (H0: 有單根/不平穩)
    pp <- pp.test(x)
    pp_stat <- paste0(round(pp$statistic, 2), ifelse(pp$p.value<0.01, "***", ifelse(pp$p.value<0.05,
"**", """)))

    # KPSS 平穩性 (H0: 平穩) - 注意：p-value 越小越不平穩
    kpss_res <- kpss.test(x, null="Level")
    # KPSS p-value 規則不同：p < 0.05 標記 * (代表不平穩)
    kpss_stat <- paste0(round(kpss_res$statistic, 3), ifelse(kpss_res$p.value > 0.1, "", "*"))

    return(c(mean_val, sd_val, min_val, max_val, jb_stat, adf_stat, pp_stat, kpss_stat))
}

target_vars <- data_clean %>% select(d_CO2, d_Total, d_Dom, d_Intl, d_EPU)
stats_table_revised <- as.data.frame(t(apply(target_vars, 2, calc_stats_revised)))
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colnames(stats_table_revised) <- c("Mean", "Std. Dev.", "Min", "Max", "Jarque-Bera", "ADF", "PP",
"KPSS")
rownames(stats_table_revised) <- c("ΔlnCO2", "ΔlnTOUR_Total", "ΔlnTOUR_Dom", "ΔlnTOUR_Int",
"ΔlnEPU")

# 匯出修正版表格
write.csv(stats_table_revised, "Table1_Revised_Full_Tests.csv")
print(stats_table_revised)

#
==========================================================================
# 5. 執行 PWC 分析與繪圖 (技術參數說明)
# ---------------------------------------------------------------------
# 依據審稿建議補充技術細節以利研究重複 (Replicability):
# 1. 母小波 (Mother Wavelet): 使用 Morlet 小波 (w0 = 6)，在時頻域具備最佳解析平衡。
# 2. 尺度解析度 (Scale Resolution): 設定為每倍頻 12 個子尺度 (dj = 1/12)。
# 3. 頻率選擇: 專注於 32-64 個月波段，對應觀光與宏觀經濟的長期循環。
# 4. 影響錐 (COI): 繪圖中淺色陰影區域代表 COI 以外，受邊際效應影響，不列入因果推論。
#
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# 1. 安裝並載入 fields 套件
if(!require(fields)) install.packages("fields")
library(fields)

# --- 全局設定 ---
par(family = "serif") # Times New Roman
my_palette <- tim.colors(64)
n_rands <- 200 # 正式跑請設 1000

# 時間軸設定
date_ticks <- seq(min(data_clean$Date), max(data_clean$Date), by = "3 years")
at_ticks <- match(date_ticks, data_clean$Date)
labels_ticks <- format(date_ticks, "%Y")

#
==========================================================================
# 圖 1: Model 1 - Total Tourism
#
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# 修改 1：將右邊界 (第 4 個數字) 從 8 縮小為 6
# 這會讓主圖向右變寬，縮小與圖例的距離
par(mfrow = c(1, 1), mar = c(3, 4, 1, 4))

pwtc_total <- pwtc(y_co2, x_total, z_epu, nrands = n_rands, dj = 1/12)

# 1. 畫主圖
plot(pwtc_total,
     plot.phase = TRUE,  # 顯示相位角 (用於領先/落後關係判讀)
     plot.cb = FALSE,
     xaxt = 'n',
     # 註解補充: 繪圖結果中，白色半透明弧線外區域為影響錐 (COI)，代表邊際效應可能導致
統計偏誤
     main = "",
     xlab = "",
     ylab = "",
     cex.axis = 1.1,
     lwd.coi = 1)
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axis(1, at = at_ticks, labels = labels_ticks, las = 1, family = "serif")

# 2. 抓取主圖座標 (確保高度對齊)
plt_coords <- par("plt")

# 3. 畫圖例 (縮小間距)
image.plot(legend.only = TRUE,
           zlim = c(0, 1),
           col = my_palette,
           legend.width = 1.2,
           # 修改 2：將 X 軸座標改為 c(0.89, 0.92) (原本是 0.92, 0.95)
           # 這樣圖例會往左靠，貼近主圖
           smallplot = c(0.89, 0.92, plt_coords[3], plt_coords[4]),
           axis.args = list(cex.axis = 0.8, family = "serif"))


#
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# 圖 2: Model 2 - Domestic Tourism
#
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par(mfrow = c(1, 1), mar = c(3, 4, 1, 4)) # 右邊界改為 6

pwtc_dom <- pwtc(y_co2, x_dom, z_epu, nrands = n_rands, dj = 1/12)

plot(pwtc_dom,
     plot.phase = TRUE,
     plot.cb = FALSE,
     xaxt = 'n',
     main = "",
     xlab = "",
     ylab = "",
     cex.axis = 1.1,
     lwd.coi = 1)

axis(1, at = at_ticks, labels = labels_ticks, las = 1, family = "serif")

# 畫圖例
plt_coords <- par("plt")
image.plot(legend.only = TRUE,
           zlim = c(0, 1),
           col = my_palette,
           legend.width = 1.2,
           smallplot = c(0.89, 0.92, plt_coords[3], plt_coords[4]),
           axis.args = list(cex.axis = 0.8, family = "serif"))


#
================================================================================
# 圖 3: Model 3 - International Tourism
#
================================================================================
par(mfrow = c(1, 1), mar = c(3, 4, 1, 4)) # 右邊界改為 6

pwtc_intl <- pwtc(y_co2, x_intl, z_epu, nrands = n_rands, dj = 1/12)

plot(pwtc_intl,
     plot.phase = TRUE,
```

```
          plot.cb = FALSE,
          xaxt = 'n',
          main = "",
          xlab = "",
          ylab = "",
          cex.axis = 1.1,
          lwd.coi = 1)

axis(1, at = at_ticks, labels = labels_ticks, las = 1, family = "serif")

# 畫圖例
plt_coords <- par("plt")
image.plot(legend.only = TRUE,
                   zlim = c(0, 1),
                   col = my_palette,
                   legend.width = 1.2,
                   smallplot = c(0.89, 0.92, plt_coords[3], plt_coords[4]),
                   axis.args = list(cex.axis = 0.8, family = "serif"))

#
==========================================================================
print("繪圖完成。圖例已向左靠攏，與主圖的間距縮小，且高度保持對齊。")

#
==========================================================================
# 6. 相位角與領先關係定量分析 (回應審稿委員：由相位角導出領先月數)
#
==========================================================================

# 定義計算函數：針對 32-64 個月波段提取平均相位
calc_lead_lag <- function(pwc_obj, model_name) {
      scales <- pwc_obj$period
      # 鎖定 32-64 個月波段
      idx_band <- which(scales >= 32 & scales <= 64)

      # 提取該波段在顯著區域內的平均相位角 (弧度)
      avg_phase <- mean(pwc_obj$phase[idx_band, ], na.rm = TRUE)

      # 轉換為領先月數 (公式: Lag = (Phase / (2*pi)) * 代表性週期)
      # 這裡使用波段中位數 48 個月作為代表性週期
      lead_months <- (avg_phase / (2 * pi)) * 48

      cat("\n---", model_name, "---")
      cat("\n 平均相位角 (弧度):", round(avg_phase, 4))
      cat("\n 在 48 個月週期下，觀光領先碳排約:", round(lead_months, 2), "個月")
      cat("\n 箭頭判讀: 向右下 (0 ~ -pi/2) 代表觀光領先碳排\n")
}

# 執行計算並輸出結果
calc_lead_lag(pwtc_total, "Model 1: Total Tourism")
calc_lead_lag(pwtc_dom,   "Model 2: Domestic Tourism")
calc_lead_lag(pwtc_intl,  "Model 3: International Tourism")

#
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#==========================================================================
# === 定量檢測疫情前後結構性轉變 (針對國際觀光 Model 3) ===
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#
#==========================================================================


# 1. 定義時間分割點 (假設 2020-01 以前為 pre, 2021-06 以後為 post 復甦期)
# 您可以根據 data_clean$Date 的索引來調整
pre_idx <- which(data_clean$Date < as.Date("2020-01-01"))
post_idx <- which(data_clean$Date >= as.Date("2021-06-01"))

# 2. 提取 32-64 個月波段的索引
# pwc_obj$period 儲存了波段長度
period_idx <- which(pwtc_intl$period >= 32 & pwtc_intl$period <= 64)

# 3. 提取相干係數矩陣 (R-squared)
# rsq 矩陣維度是 [period, time]
r2_matrix <- pwtc_intl$rsq[period_idx, ]

# 4. 計算兩個時期的平均相干性 (排除 COI 以外的無效值)
avg_r2_pre <- mean(r2_matrix[, pre_idx], na.rm = TRUE)
avg_r2_post <- mean(r2_matrix[, post_idx], na.rm = TRUE)

# 5. 進行統計檢定 (證明這不是隨機發生的)
# 將矩陣拉平進行比較
r2_pre_values <- as.vector(r2_matrix[, pre_idx])
r2_post_values <- as.vector(r2_matrix[, post_idx])

t_test_res <- t.test(r2_post_values, r2_pre_values)

# 6. 輸出結果
cat("\n--- 國際觀光結構轉變定量分析 ---")
cat("\n 疫情前平均相干性 (Pre-pandemic R2):", round(avg_r2_pre, 4))
cat("\n 疫情後平均相干性 (Post-pandemic R2):", round(avg_r2_post, 4))
cat("\n 相干性增長百分比:", round((avg_r2_post - avg_r2_pre)/avg_r2_pre * 100, 2), "%")
cat("\nP-value (t-test):", t_test_res$p.value)

if(t_test_res$p.value < 0.01) {
    cat("\n 結論：統計結果證實國際觀光與碳排之關係存在顯著的結構性轉變。")
}

#==========================================================================
# === 國際 vs 國內觀光：後疫情復甦定量對比分析 (2021-2025) ===
#
#==========================================================================

# 1. 建立後疫情時代數據子集 (2021 年 1 月至數據結束)
post_recovery_data <- data_clean %>% filter(Date >= as.Date("2021-01-01"))

# 2. 計算恢復成長率 (與 2020 年疫情低點平均值相比)
# 計算 2020 年的平均值作為基準
base_2020_dom <- mean(raw_data$DOMESTIC[raw_data$Year == 2020], na.rm=TRUE)
base_2020_intl <- mean(raw_data$INTERNATIONAL[raw_data$Year == 2020], na.rm=TRUE)

# 獲取最新的觀光水平 (數據最後一筆)
current_val_dom <- tail(raw_data$DOMESTIC, 1)
current_val_intl <- tail(raw_data$INTERNATIONAL, 1)

# 計算成長百分比
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growth_dom <- (current_val_dom - base_2020_dom) / base_2020_dom * 100
growth_intl <- (current_val_intl - base_2020_intl) / base_2020_intl * 100

# 3. 提取小波分析中的平均相干性 (R2) - 針對 32-64 個月核心波段
# 確定 2021 年後的時間索引
idx_2021_plus <- which(data_clean$Date >= as.Date("2021-01-01"))
# 確定 32-64 個月的頻率索引
idx_period <- which(pwtc_total$period >= 32 & pwtc_total$period <= 64)

# 提取相干性 R2 並計算平均值
r2_post_dom <- mean(pwtc_dom$rsq[idx_period, idx_2021_plus], na.rm = TRUE)
r2_post_intl <- mean(pwtc_intl$rsq[idx_period, idx_2021_plus], na.rm = TRUE)

# 4. 產出比較結果表格
comparison_table <- data.frame(
    Metric = c("Recovery Growth Rate (vs. 2020 avg)", "Mean Coherence (R2) with CO2"),
    Domestic_Tourism = c(paste0(round(growth_dom, 2), "%"), round(r2_post_dom, 4)),
    International_Tourism = c(paste0(round(growth_intl, 2), "%"), round(r2_post_intl, 4))
)

# 5. 輸出表格
cat("\n--- Table 2: Quantitative Comparison of Post-Pandemic Recovery Flows ---\n")
print(comparison_table)

# 輸出統計顯著性檢定 (針對 R2 差異)
t_test_comp <- t.test(as.vector(pwtc_intl$rsq[idx_period, idx_2021_plus]),
                      as.vector(pwtc_dom$rsq[idx_period, idx_2021_plus]))
cat("\nP-value for R2 difference between Intl and Dom:", t_test_comp$p.value)

#
```